

Soil Contamination with Heavy Metals around Jinja Steel Rolling Mills in Jinja Municipality, Uganda

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Introduction

Soil contamination with heavy metals has severely increased over the last decades, mainly from industrial wastes and human activities.^{1,2} Soil pollution by heavy metals is as a result of both natural processes such as weathering of minerals, and anthropogenic activities related to industries, fossil fuel burning, emissions from vehicles, mining, agriculture and metallurgical processes and their waste disposal.³ The production of steel is vital for the economic growth of Uganda, but its production is a major source of pollution.⁴ Solid and liquid wastes, including fumes generated from the steel plant and the raw materials, usually contain notable amounts of heavy metals such as arsenic (As), cadmium (Cd), mercury (Hg),

Background. Soil contamination with heavy metals has severely increased over the last few decades, mainly from industrial wastes and human activities. Soil pollution is a source of danger to the health of people globally.

Objectives. To assess the level of soil contamination with heavy metals around steel rolling mills in Jinja municipality, Uganda.

Methods. Four composite soil samples were collected from each of the sides of the Jinja steel rolling mills, dried and digested. The digested solution samples were analyzed in triplicates for the levels of lead (Pb), zinc (Zn), cadmium (Cd), chromium (Cr), copper (Cu), and nickel (Ni), using a flame atomic absorption spectrometer (Savant AA model 2009); the analytical process was monitored using analytical standard solutions. Data analysis was performed using Statistical Package for the Social Sciences (SPSS) software version 19 and Excel. Mean metal concentrations, standard deviations, medians, and skewness were obtained to describe heavy metal concentrations in the soil. Pollution load index and geo-accumulation indices were calculated to determine the level and extent of heavy metal contamination in the soil.

Results. The mean concentration loads of the heavy metals in soils around the Jinja steel rolling mills were 43.15 mg/kg for Pb, 28.16 mg/kg for Zn, 0.93 mg/kg for Cd, 0.22 mg/kg for Cr, 80.96 mg/kg for Cu, and 9.40 mg/kg for Ni. The metal load distribution around the industry was in descending order: Left-hand side > Downwind side > Right-hand side > Upwind side. Results for the geo-accumulation index were 1.30 for Pb, -1.31 for Zn, 2.63 for Cd, -7.25 for Cr, 2.99 for Cu, and -1.19 for Ni. The overall pollution load index was 1.08.

Conclusions. The concentration levels of heavy metals around the steel rolling mills did not appear to be of serious concern, except for copper and cadmium, which showed moderate pollution and moderate to strong pollution, respectively. All heavy metals were within the limits of the United States Environmental Protection Agency (USEPA) residential soil standards and the Dutch intervention soil standards. Overall, soils around the Jinja steel rolling mills were slightly polluted with heavy metals, and measures therefore need to be taken to prevent further soil contamination with heavy metals.

Competing Interests. The authors declare no competing financial interests.

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manganese (Mn), copper (Cu), cobalt (Co), nickel (Ni), zinc (Zn), lead (Pb), and bismuth (Bi), among others, which may be released into the environment and cause environmental health problems.⁴

Soil pollution is a source of danger to the health of people worldwide. Soil contamination with heavy metals such as Cd, Cu, chromium

(Cr), Pb, Ni and Zn in terrestrial ecosystems has been recognized as a serious environmental health concern due to the non-biodegradability of these heavy metals and tendency to accumulate in plants and animal tissues, which later enter into the human food chain and may result in health problems.⁵ This food chain contamination is an important pathway for the entry of these toxic

pollutants into the human body. Chronic intakes of toxic metals have adverse impacts on humans which may become apparent only after several years of exposure.⁶ The consumption of heavy metal-contaminated food can seriously deplete some essential nutrients in the body that are further responsible for decreasing immunological defenses, intrauterine growth retardation, impaired psycho-social faculties, disabilities associated with malnutrition and a high prevalence of upper gastrointestinal cancer rates.⁷

The Jinja steel rolling mills (SRM) are part of one of the fast growing industries in Jinja and Uganda. However, there is limited documented information on the level of soil contamination with heavy metals around the Jinja steel rolling mills. Therefore, the aim of this study was to generate information on the level and extent of soil contamination with heavy metals around the Jinja steel rolling mills, Uganda.

Methods

Study Area

The present study was conducted around the Jinja SRM in Jinja municipality, Uganda. Jinja lies in southeastern Uganda, approximately 54 miles (87 km) by road, east of Kampala, the capital city of Uganda. The town is located on the shores of Lake Victoria, near the source of the River Nile. The area has warm temperatures ranging between 23°C to 32°C and a bi-modal rainfall pattern averaging approximately 1260 mm annually. The soils in the area are characterized by granites and granitoid gneisses. Part of the industrial area soils are composed of shales, phillites and schists.⁸ The Jinja steel rolling mills are the leading producer of steel products in Uganda; they are surrounded

Abbreviations			
As	Arsenic	I_{geo}	Geo-accumulation index
Bi	Bismuth	Mn	Manganese
Bn	Geochemical background values of metals	n	Number of metals investigated in the soil
Cd	Cadmium	Ni	Nickel
CF	Contamination factor	Pb	Lead
Cm	Measured total concentrations of metals in soils	PLI	Pollution load index
Co	Cobalt	SPSS	Statistical Package for the Social Sciences
Cr	Chromium	SRM	Steel rolling mills
Cu	Copper	USEPA	United States Environmental Protection Agency
EDTA	Ethylene-diaminetetra-acetic acid	WEPAL	Wageningen Evaluating Programs for Analytical Laboratories
Fe	Iron		
Hg	Mercury	Zn	Zinc

by farming communities and Lake Victoria. The upwind side of the factory is plain land, with the Busoga Forestry Company Ltd. 350 miles away from the SRM; the downwind side is near the main highway and small cultivations are carried out on that side. The right-hand side of the factory is mainly a settlement area, with small-scale cultivation, while the left-side is a business area with a road network connecting to the factory.

SRM uses iron ore as the main raw material which is stored in the open, at the peripheral ends of the factory before it is fed into the manufacturing process. The iron ore is reduced

using coal in a rotary kiln to form sponge iron, releasing fumes into the environment. The sponge iron is melted and upgraded to form mild steel, which is cast into billets through a billet casting machine. The billets are reheated in a reheating furnace using fuel furnace oil and then rolled at the rolling mills into bars. Very minimal liquid waste is generated.

Soil Sampling

Four composite soil samples to a depth of 15 cm were collected from each of the four different sides of the factory (upwind, downwind, right- and left-hand sides) during March 2015. Four discrete sub-



Figure 1 — Map of the study area showing sampling locations

samples made up a composite sample. The compositing procedure was done following the United States Environmental Protection Agency (USEPA) guidelines.⁹ The compositing tools were washed with tap water and air dried prior to sampling, and four sub samples were collected using a screw auger of 8 cm diameter, mixed using a stainless steel fork to form homogeneous composite samples, which were stored in properly labeled polyethylene bags and transported to the laboratory. All field activities, observations, sample labeling, and the corresponding sides of the factory were recorded. The composite samples were labeled U1, U2, U3 and U4 for upwind

composites; D1, D2, D3 and D4 for downwind composites; L1, L2, L3 and L4 for left-side composites; and R1, R2, R3, and R4 for right-side composites.

Chemical Analysis

The four composite soil samples from each sides of the factory were air dried at 40°C for 48 hours, disaggregated with a mortar and pestle and then sieved through a 150-mesh stainless-steel screen. Triplicates of 5 g of each of these composite samples were digested with a concentrated solution of ethylene-diaminetetra-acetic acid (EDTA) and topped up with distilled water (40 mL). The soil digested solutions

were cooled to room temperature, filtered and transferred to plastic vials before metal analysis; the digestion was performed according to the laboratory methods of the Soil and Plant Analysis Working Manual, second edition.¹⁰ Quantification of the heavy metal content (i.e. Cd, iron (Fe), Cu, Ni, Pb, Zn and Cr) of the digested samples was carried out with a flame atomic absorption spectrometer (GBC Savant AA Model 2009), which was earlier calibrated using prepared standard solutions of 0.0, 0.2 ppm, 0.4 ppm, 1 ppm, 2 ppm and 5 ppm for the respective metals. The calibration graphs of concentration of the standards against absorbance were plotted, from which the concentrations of the corresponding elements were read by extrapolation or interpolation. The laboratory obtained its certifications and analytical standards from Wageningen Evaluating Programs for Analytical Laboratories (WEPAL).

Quality Control

During the experiment, principles of quality assurance/quality control were applied to ensure improved accuracy and precision of results. These principles included washing all the glassware with dilute hydrochloric acid, and use of well-calibrated volumetric glassware.

The Atomic Absorption spectrometer was calibrated using a freshly prepared standard solution of the corresponding heavy metals. In this study, standard reference materials (JG-3) were used.¹¹ Precision of the analytical results was estimated by replicate analysis.

Data Analysis

Data analysis was performed using SPSS software version 19 and Excel; mean metal concentrations, standard deviations, medians, and skewness were obtained to describe heavy metal

concentrations in the soil. Pollution load index and geo-accumulation indices were calculated to determine the level and extent of heavy metal contamination in the soil.

To assess the extent of contamination, pollution load index (PLI) using Tomlinson's approach was used.⁶ The PLI represents the number of times by which the metal content in the soil exceeds the average natural background concentration, and gives a summative indication of the overall level of heavy metal toxicity in a particular sample. The concentrations in reference materials were taken to represent natural background concentrations. When $PLI > 1$, then the soil is polluted; and when $PLI < 1$, there is no metal pollution.¹²

The PLI is obtained as a contamination factor (CF) of each metal with respect to the natural background value in the soil, given as $(CF \times CF \times \dots)^{1/n}$, where CF is the contamination factor which is given as mean metal concentration in soils divided by natural background concentrations and the solution is number of metals investigated in the soil (n).¹³

The geo-accumulation index (I_{geo}) was used to determine the level of soil contamination with the different heavy metals. The I_{geo} for heavy metal is calculated by computing the base 2 logarithm of the measured total concentration of the metal over its background concentration using the following mathematical expression: $I_{geo} = \log_{\text{base } 2} (C_m / 1.5B_n)$, where C_m is the measured total concentrations of metals in soils, B_n is the geochemical background values of metals and 1.5 is the background matrix correction factor due to lithogenic effects.^{14,15} The I_{geo} interpretation according to Lu was adopted for this study; $I_{geo} < 0$ = practically unpolluted; $0 <$

$I_{geo} < 1$ = unpolluted to moderately polluted; $1 < I_{geo} < 2$ = moderately polluted; $2 < I_{geo} < 3$ = moderately to strongly polluted; $3 < I_{geo} < 4$ = strongly polluted; $4 < I_{geo} < 5$ = strongly to extremely polluted; and $I_{geo} > 5$ = extremely polluted.¹⁶

Results

Metal Concentration Distributions around the Factory

The right-hand side of the factory had the lowest mean concentrations (mg/kg) for all heavy metals, however, based on the PLI, the left-hand side of the factory had the highest heavy metal load, in the following order: Left-hand side > Downwind side > Right-hand side > Upwind side. The left-hand side was slightly polluted ($PLI > 1$). The upwind side had the highest concentrations of Pb (56.69 mg/kg) and Zn (30.05 mg/kg), with no Cr. The downwind side had the highest concentrations of Cd (1.93 mg/kg) and Cu (94.75 mg/kg), while the left-hand side had the highest concentrations of Cr (0.60 mg/kg), and Ni (10.82 mg/kg). All of the metals were below the limits according to USEPA residential soil standards and the Dutch intervention standards of soil (Table 1).^{17,18}

Level and Extent of Soil Contamination with Heavy Metals

From Table 3, the results of the geo-accumulation indices for Zn, Cr, and Ni were less than 0, indicating that the soils were unpolluted with these metals. The soils were moderately polluted with Cd ($1 < I_{geo} < 2$) and moderately to strongly polluted with Cu ($2 > I_{geo} < 3$). The order of contribution of various heavy metals to soil contamination on the basis of I_{geo} follows: Cu > Cd > Pb > Ni > Zn > Cr. The overall pollution load index indicated that the soils surrounding the factory were slightly polluted with heavy metals ($P = 1.08$).

Discussion

The left-hand side of the factory had the highest heavy metal load as compared to the downwind side of the factory. This could be attributed to the road network on the left-hand side of the factory that supplies raw materials to the factory, and therefore the high heavy metal load on this side could be due to anthropogenic effects such as burning of fossil fuel, wear and tear of tires, and dust generation during transportation of raw materials. This finding is consistent with that of studies in the US, where soils lying in the vicinity of highways were found to have high metal concentrations.¹⁹ Also, the high perimeter wall on the downwind side of the factory could have contributed to low metal concentrations on that side since wind had less of an effect in depositing metal dust on that side.

The concentration levels of heavy metals around the factory did not appear to be of serious concern, except for Cu and Cd, for which the I_{geo} indicated that they were moderately polluted and moderately to strongly polluted, respectively. However, Cu and Cd concentrations were below the reference levels for metal contamination in soils of both USEPA residential soil standards and Dutch intervention standards for soils.^{17,18} The concentration of Cd in this study was higher than the concentrations reported in Sweden (0.4 mg/kg) and Denmark (0.8 mg/kg).²⁰ The high levels of Cd could be attributed to traffic and use of fertilizer by farmers around the factory.

The soils around the factory were slightly polluted with heavy metals ($PLI = 1.08$). These study findings were in contrast to study findings around the industrial area in Kampala, Uganda where the PLI showed heavy soil

Side of the factory	Sampling Sites	Heavy metal mean concentrations (mg/kg)						PLI
		Pb	Zn	Cd	Cr	Cu	Ni	
Right-hand side	R1	28.98	25.45	0.21	0.28	58.46	9.46	
	R2	31.45	27.78	0.34	0.22	62.87	10.98	
	R3	29.46	24.39	0.28	0.25	57.47	10.25	
	R4	31.39	28.86	0.17	0.17	60.88	9.79	
	Average	30.32	26.62	0.25	0.23	59.92	10.12	0.79
Left-hand side	L1	45.68	27.95	0.68	0.63	74.8	9.82	
	L2	49.53	30.24	0.59	0.71	77.45	11.34	
	L3	46.58	25.83	0.73	0.54	73.86	10.74	
	L4	50.01	28.06	0.56	0.52	75.45	11.38	
	Average	47.95	28.02	0.64	0.6	75.39	10.82	1.23
Upwind side	U1	55.76	29.45	0.74	0.00	92.34	7.43	
	U2	58.26	32.18	1.13	0.00	93.54	9.55	
	U3	54.83	27.54	0.85	0.00	95.45	8.23	
	U4	57.91	31.03	1.00	0.00	93.79	9.63	
	Average	56.69	30.05	0.93	0.00	93.78	8.71	0.00
Downwind side	D1	39.24	28.29	1.76	0.06	95.74	8.35	
	D2	37.68	31.41	1.89	0.08	93.67	8.19	
	D3	35.46	24.59	2.04	0.01	92.45	7.64	
	D4	38.22	27.55	1.99	0.01	97.14	7.66	
	Average	37.65	27.96	1.92	0.04	94.75	7.96	0.89
USEPA residential soil standards		400	23,600	70	230	—	1,600	
Dutch intervention standards for soil		530	720	12	380	190	210	

Table 1 — Mean Metal Concentrations (mg/kg) around the Factory

pollution with heavy metals.²¹ It was also contrary to the findings in western India and in Nigeria, where heavy soil contamination with heavy metals was reported.^{22,23} The low pollution level in this study could be due to the high perimeter wall that was observed around the factory, and it was also reported that all fumes and gases are passed through dust collectors before being released into the environment.

However, these results were obtained in soils around a steel processing factory, and thus these results may not be generalized for all industries in the country.

Conclusion

The study revealed that the left-hand side of the factory had the highest heavy metal load, in the following

order: Left-hand side > Downwind side > Right-hand side > Upwind side. The overall heavy mean metal concentration around the factory was in the descending order Cu > Pb > Zn > Ni > Cd > Cr. The I_{geo} indicated that soils were moderately polluted with Cd ($1 > I_{geo} < 2$) and moderately to strongly polluted with Cu ($2 > I_{geo} < 3$) and overall, soils around the industry were slightly polluted with

	Pb	Zn	Cd	Cr	Cu	Ni
Mean	43.15	28.16	0.93	0.22	80.96	9.40
Median	42.80	27.99	0.78	0.14	84.58	9.41
Standard deviation	11.57	1.41	0.71	0.27	16.61	1.30
Maximum	56.69	30.05	1.92	0.60	94.75	10.82
Minimum	30.32	26.62	0.25	0.00	59.92	7.96
Skewness	0.13	0.72	1.12	1.29	-0.69	-0.03
USEPA residential soil standards	400	23,600	70	230	—	1,600
Dutch intervention soil standards	530	720	12	380	190	210

Table 2 — Statistical Summary of Metal Concentrations (mg/kg) in Soil

Metal	Concentration mg/kg	Natural background concentrations mg/kg	Contamination factor	Geo-accumulation indices
Pb	43.15	11.70	3.69	1.30
Zn	28.16	46.50	0.61	-1.31
Cd	0.93	0.10	9.30	2.63
Cr	0.22	22.40	0.01	-7.25
Cu	80.96	6.81	11.89	2.99
Ni	9.40	14.30	0.66	-1.19

Table 3— Contamination Factor and Geo-accumulation Indices of Metals in Soil
Overall pollution load index =1.08

heavy metals (PLI = 1.08). The steel mill does not appear to be causing significant heavy metal pollution in the neighboring areas, which may be due to effective air pollution controls and relatively low heavy metal concentrations in the iron ore and coal that is used. However, examining the main reasons for the low metal contamination around these soils would require intrusive evaluation

inside the factory and is beyond the scope of this paper.

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